What Do We Want to Know Before TPF/Darwin Fly?

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27 July 2004

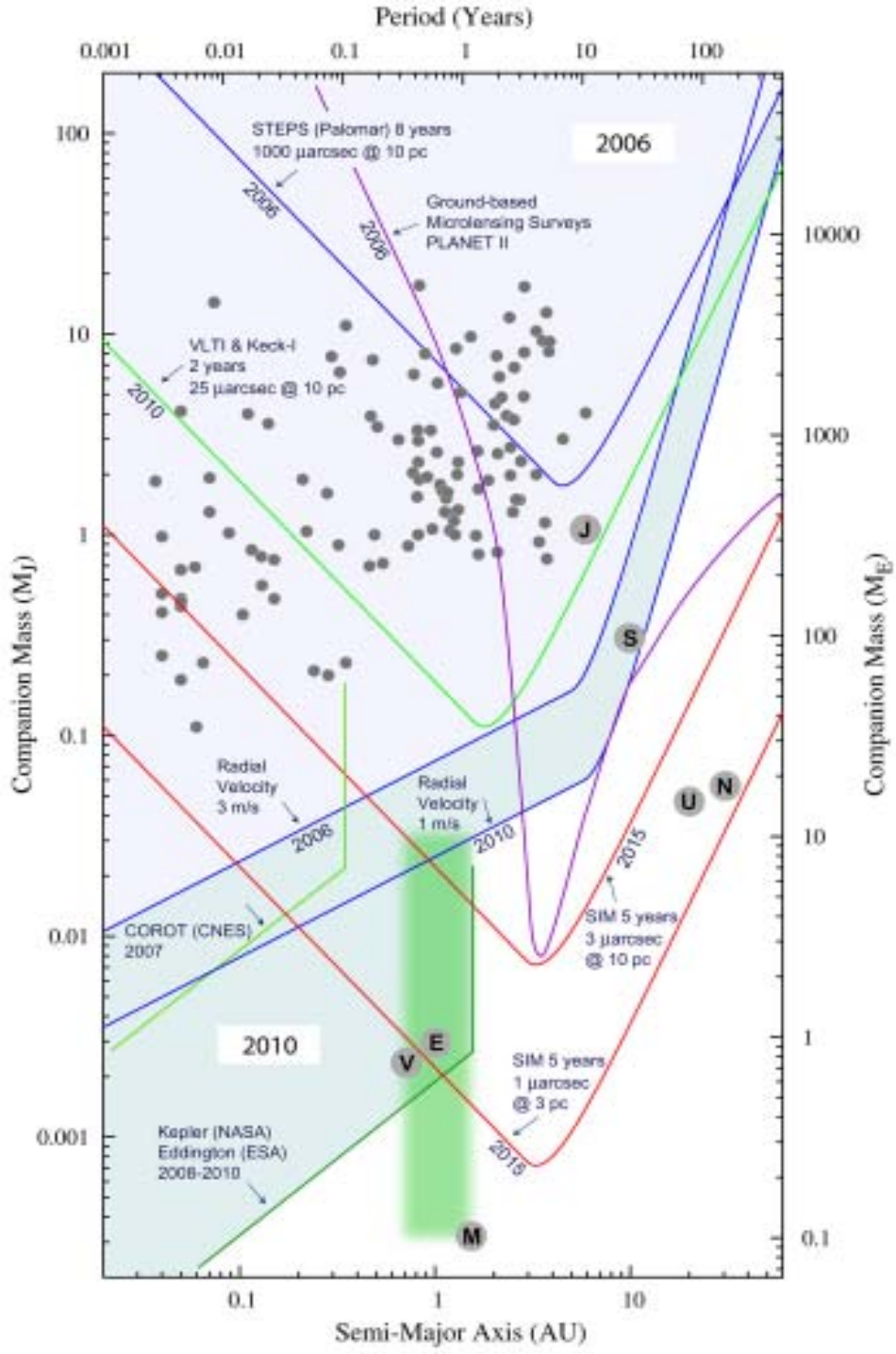
With lots of help on Spitzer from G. Bryden, the MIPS Instrument team, Peter Lawson, the SIM-TPF Disks team, and Beth Holmes (1974-2004)

Focus of Precursor Science Activities

- Identify the best targets
  - Dynamically hospitable stars for habitable zone planets
  - Low exo-zodiacal emission for planet detectability
- Characterize parent stars in terms of detectability, but also to highlight systems that might harbor habitable earths or support life
  - Spectral type, metallicity, X-ray activity, age, rotation
  - Dynamical environment including presence/absence of outer giant planets and their orbital properties (radius and eccentricity)
  - Other solar system constituents, e.g. comets and asteroid belts
- Develop the TPF/Darwin science community
  - Instrumentalists
  - Observers
  - Theoreticians

Incidence of Planets: Near and Far

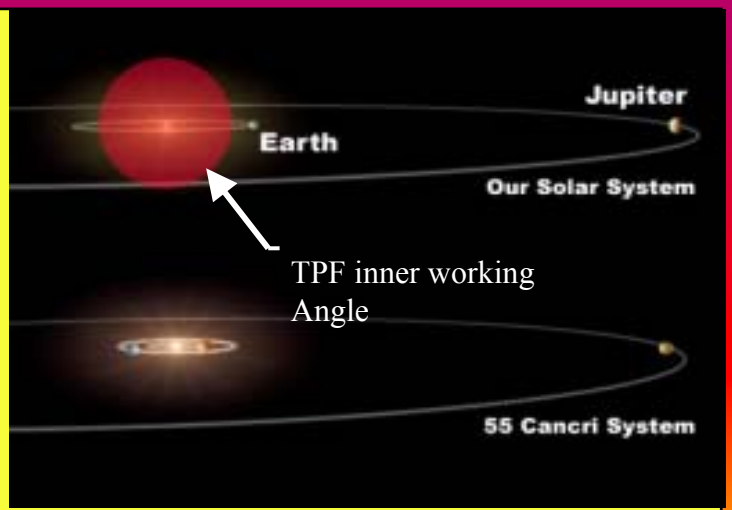
- Statistical knowledge
  - Improving sensitivity and temporal baseline for RV may yield planets with 10 Earth Mass at <1 AU
  - Transit experiments (MOST, COROT, Kepler/Eddington) will determine incidence of 1~few Earth masses at orbits 0.1~1 AU
  - Ground-based mircolensing might find few earth mass planets around distant stars
- Targeting specific stars for TPF/Darwin operations
  - Radial velocity on long temporal baselines and greatest sensitivity
  - Extreme AO/coronagraphy on large 10-30 m ground-based to find gas giants
  - Astrometry from Keck-I/VLT-I/SIM to pre-select best/worst targets



SIM And TPF Yield A Complete Survey For Earths

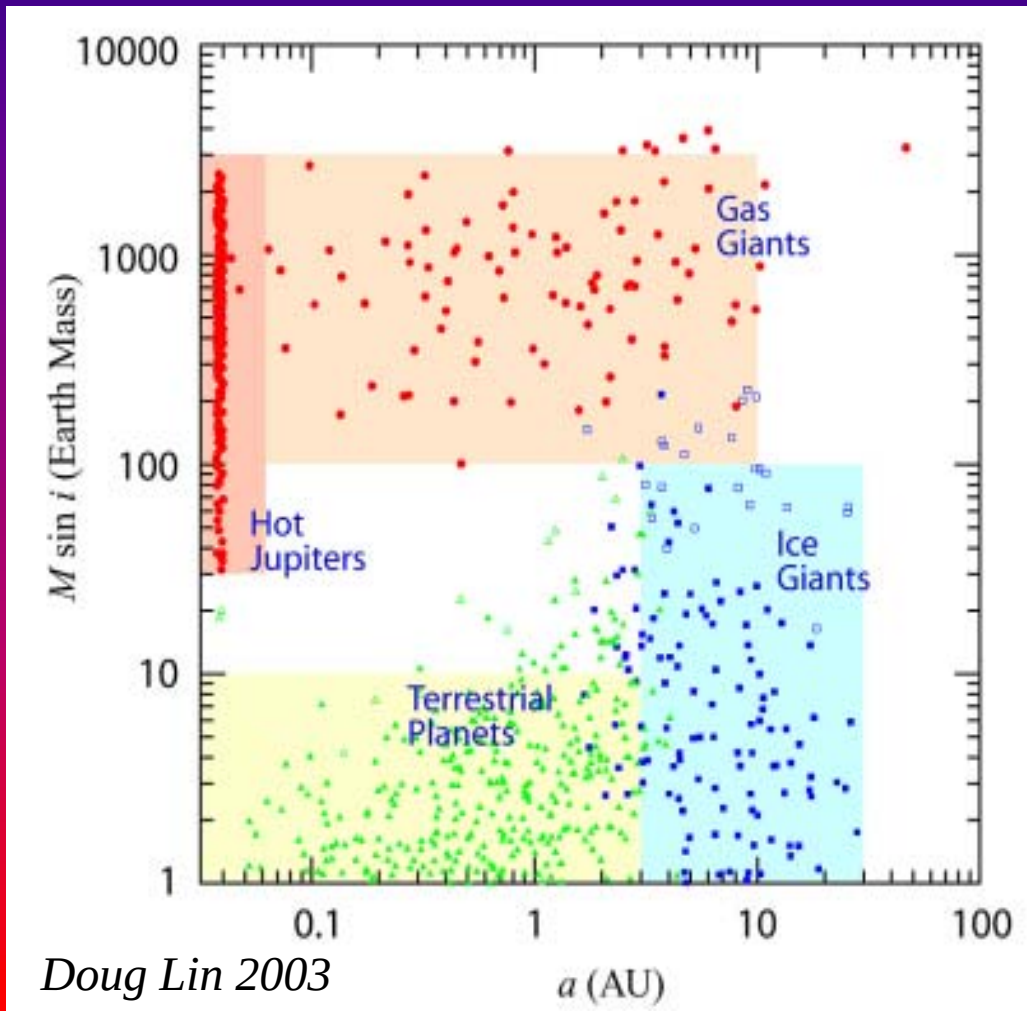
- SIM will search ~250 closest stars for presence of terrestrial planets (<10M $_{\oplus}$):
  SIM limit: 3 M $_{\oplus}$ @10 pc, 5 yrs (5σ).
  1.5M $_{\oplus}$ @ 10 pc, 10 yr (5σ)
- SIM will identify the best targets for TPF/Darwin
  - 1) *Definite targets*: detect terrestrial-mass planets in the habitable zones of nearby stars
  - 2) *Potential targets*: identify stars where terrestrial planets can exist in habitable zones, in stable orbits.
  - 3) *Low priority targets*: where SIM sees no sign of terrestrial planet (2σ ~1.2M $_{\oplus}$).
  - 4) *Avoid targets*: where SIM finds a giant planet in the habitable zone (10-30 M$_{\oplus}$, below RV limits)

- Orbits from SIM will enable timing TPF/Darwin observations to catch planets at maximum elongation for optimum TPF observational efficiency and completeness



Important Role for Theory

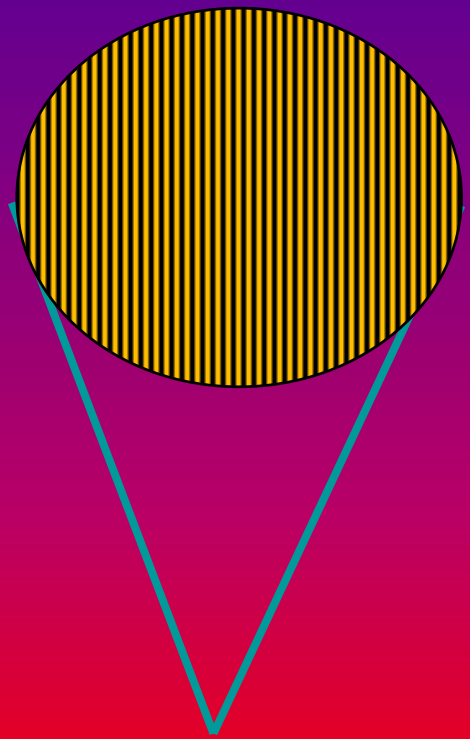
- Theory combines disparate data to permit extrapolation from known incidence of planets to desired range of (mass, orbit) for habitable planets for TPF
  - Formation scenarios for gas giant, icy (oceanic) and rocky planets
  - Orbital migration
  - Theory (Lin, Lunine, Tremaine, et al) suggest $\eta_{\oplus} > 0.1$
- Investigate long term dynamical stability of earths in potential targets
- Link observations of Kuiper Belts, zodiacal clouds, gas giants to predict EZ in potential targets

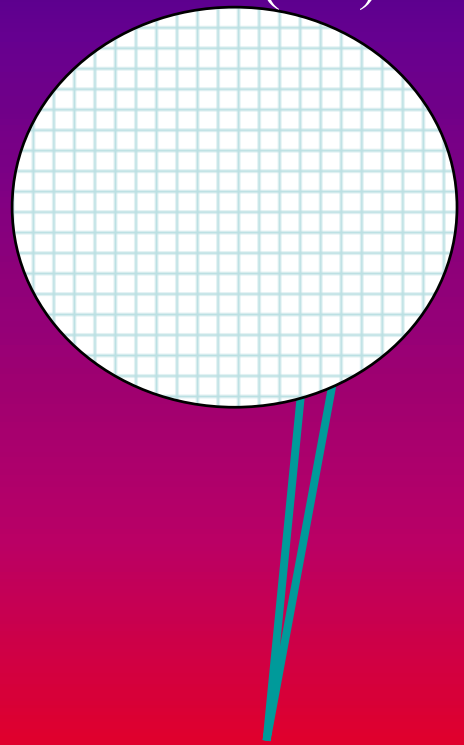


Doug Lin 2003

Exo-Zodiacal Emission: Noise Source For Both Architectures

- Architectural difference between Interferometer and Coronagraph is how they see exo-zodiacal (EZ) emission

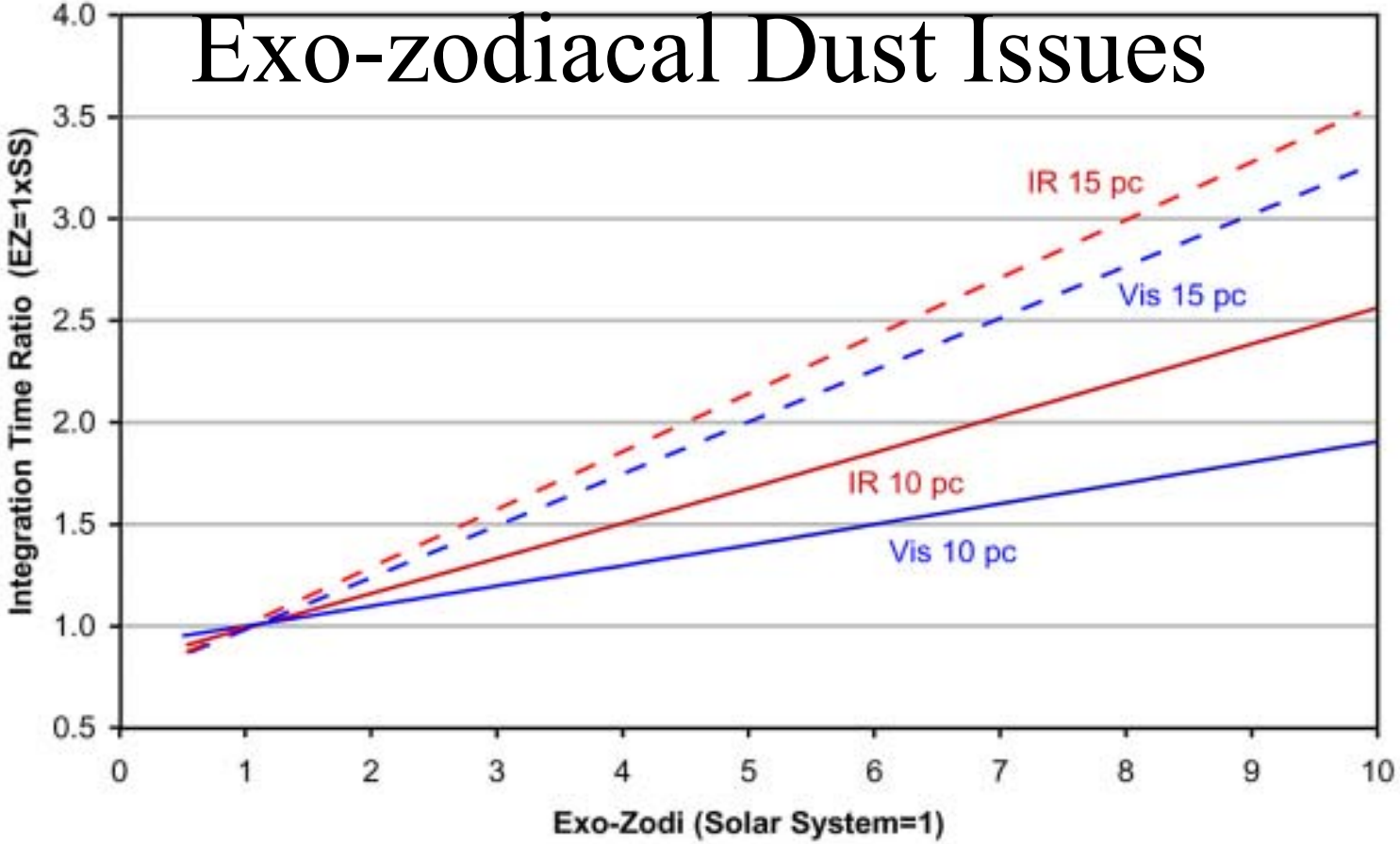




Interferometer takes in entire EZ
Resolution: 50 mas = 0.5 AU but
FOV: 0.5 λ/D=1.5”=+/-7.5 AU
For 4 m telescope at 10 μm at 10 pc

Coronagraph resolves EZ
Image size: 50 mas = 0.5 AU
For 5 m telescope at 0.5 μm
at 10 pc

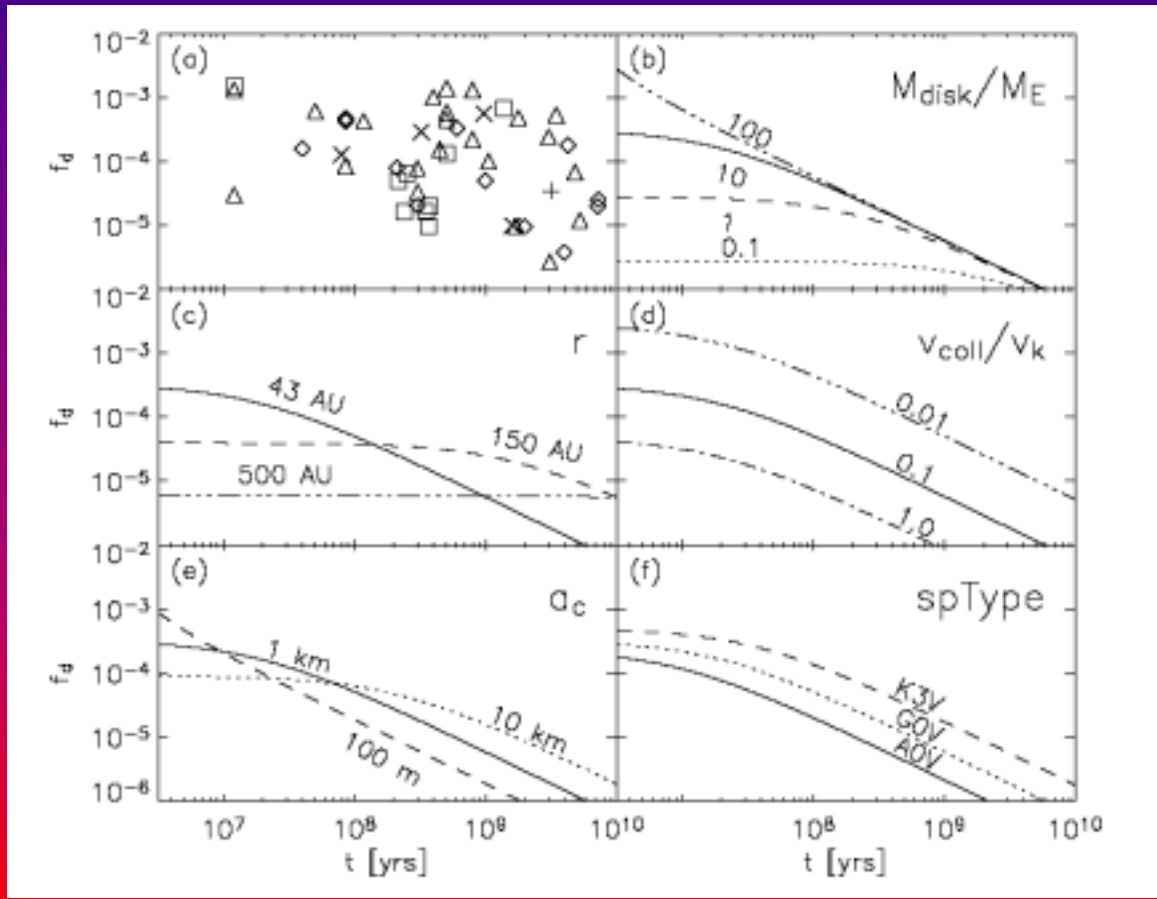
Exo-zodiacal Dust Issues



- Interferometer and coronagraph can operate at zodiacal dust levels $\leq$10× level in our system with modest impact on integration time ($\leq$3×)
- SIRTF will characterize Kuiper Belts of TPF targets
- Keck-I, LBT-I and VLT-I will characterize the inner exozodi at 10 μm to a level of 10 zodis.
- The early statistics (50 stars) will show extent to which exo-zodi likely to a problem for the whole TPF target sample (>10x solar system)

Exo-Zodiacal Clouds and Youth

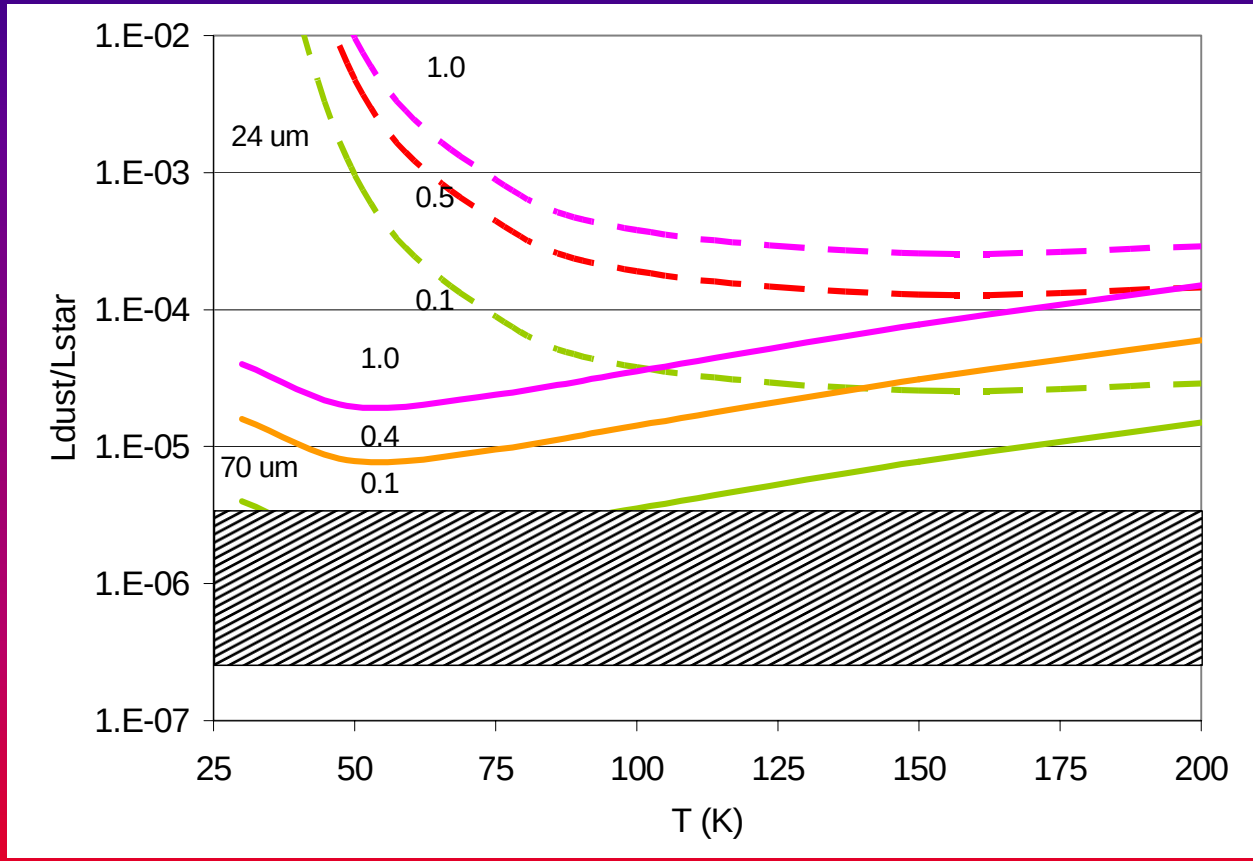
- ISO data from Habing et al (2000), Spangler et al (1998) suggest substantial disks vanish by <400 Myr
  - –Domenick, Decin et al (2003) find ~t^{-1} suggesting collisional cascade. Not t^{-2}
- Spitzer (Rieke et al 2004) suggests disks gone by 100 Myr (at 24 μm)
  - – Broad dispersion above minimum line suggests sporadic outbursts (Backman et al)
- Spitzer/MIPS and IRS will expand statistics and push down limits



Domenik and Decin Ap.J. 2003

Exo-zodiacal Observations from Space

- Space observatories are "resolution-challenged" and "photometry-limited" to $10^{2\text{-}3}\times$ dust in habitable zone and $10^{1\text{-}2}\times$ dust in our Kuiper Belt.



Spitzer sets limits on dust of different temperature

Exo-Zodiacal Clouds and Planets

- Volume limited sample (VLS) targets 150 stars including 38 stars with RV planets. About 1/3 of data are available.
- With poor statistics so far, the rate of finding excesses at 70 μm is doubled by presence of planets (2/13 vs. 3/38; 15% vs. 8%)
- Considerably greater disparity in rates if: a) only older stars are considered; b) probable detections are included; c) "non-planet" stars turn out to have planets.

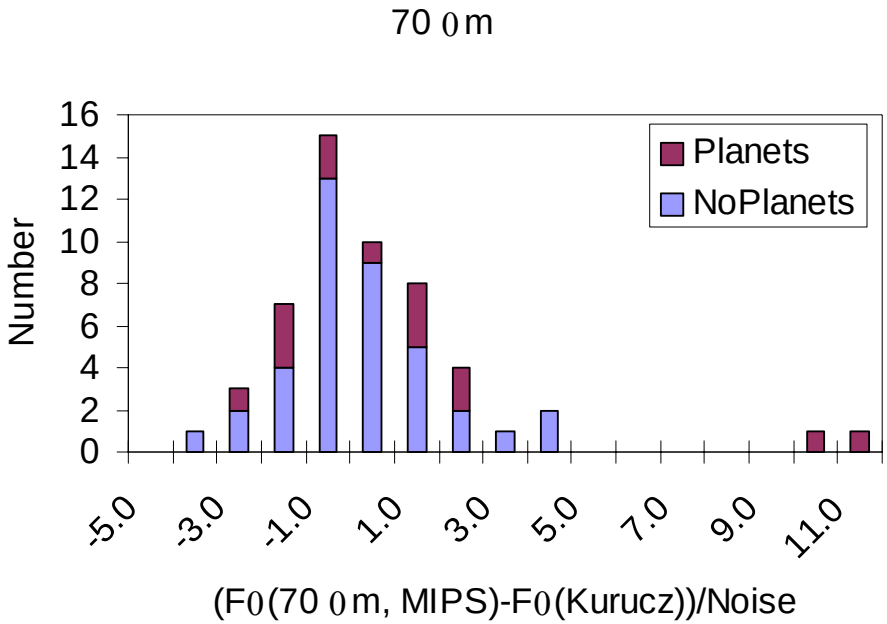
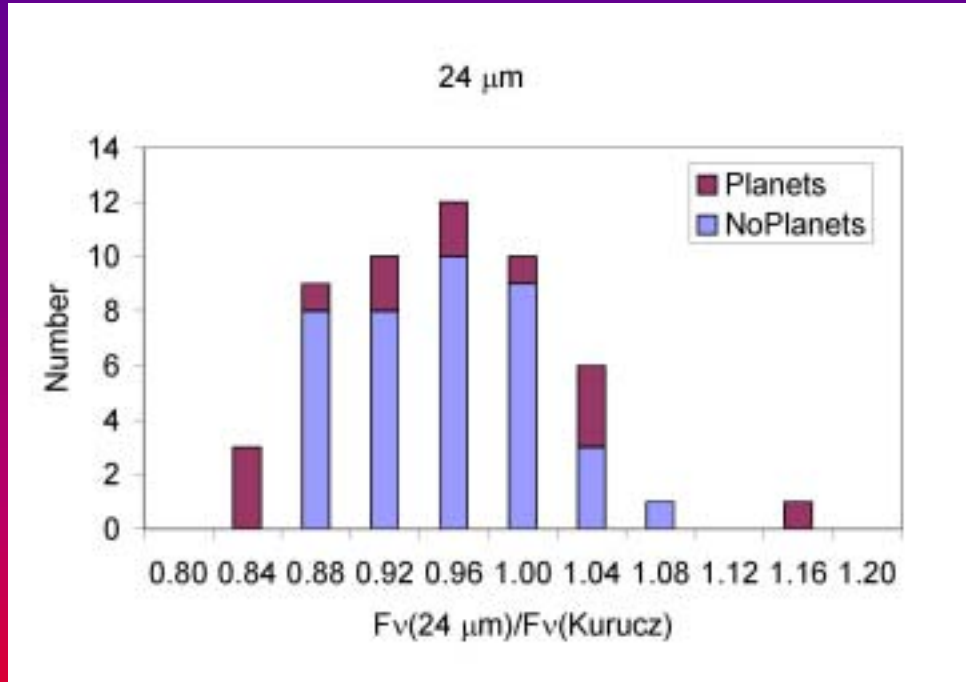


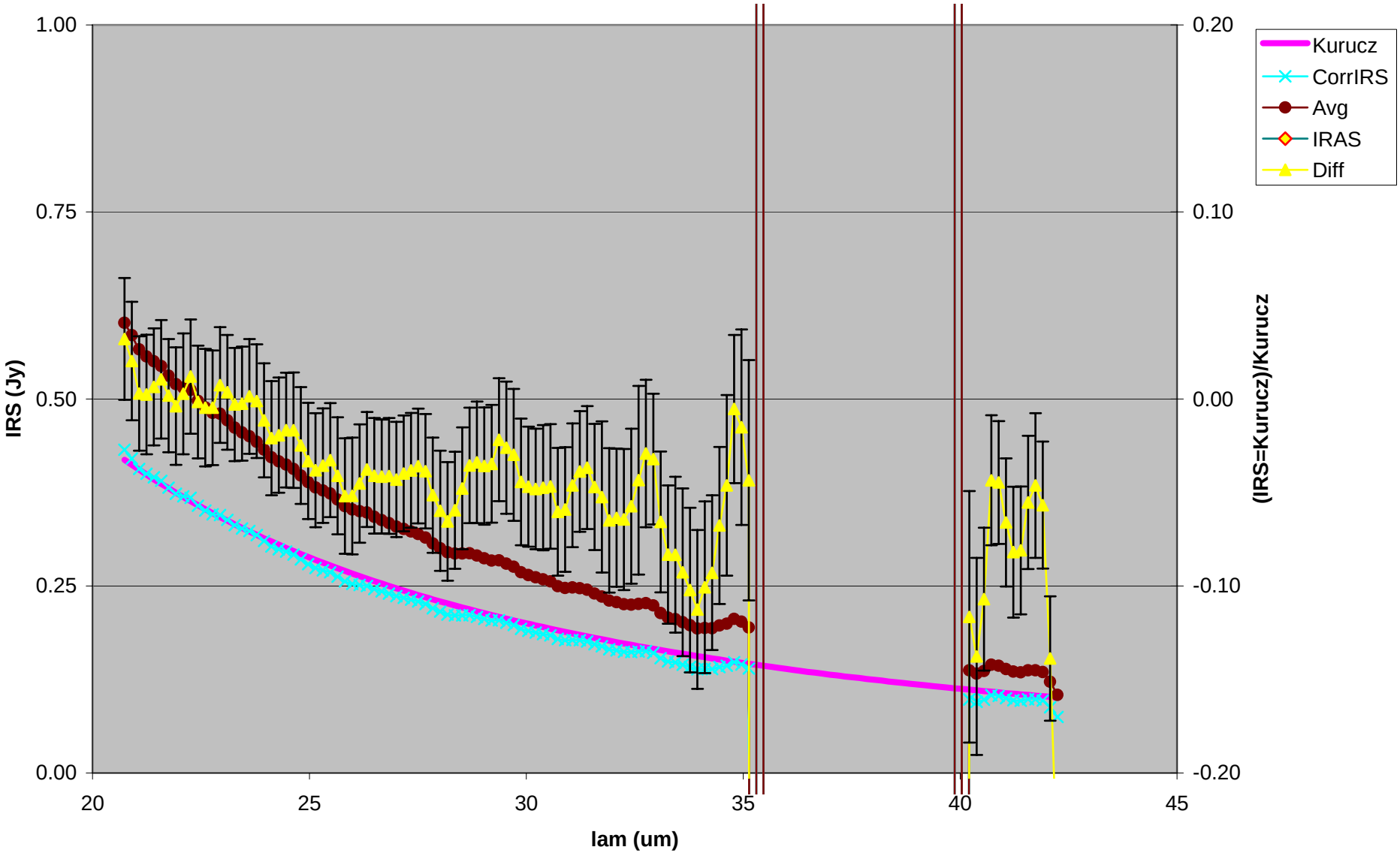
Table 1. Statistics of Partial VLS Survey	
Total Stars Observed	53
Stars with no known planets	39
Detections	35
Strong Upper limits	3
Firm Excesses	3
Stars with known planets	14
Detections	10
Strong Upper limits	3
Firm Excesses	2
Possible Detections	3

MIPS 24 μm Sets Limit on Dust Around Habitable Zone

- Our zodiacal cloud is located at 0.1-3 AU
  - Emission peaks around 25 μm (IRAS and COBE)
- IRAS showed that 25 μm excesses were rare, ~1% of FGK stars
- Spitzer/MIPS consistent with IRAS
  - Only 1 *possible* excess at 24 μm out of 53 stars
  - Planet bearing star
  - No excess at 70 μm
- Hot dust at 10^{-3} to 10^{-4} level is rare
- Good, but not definitive for TPF



IRS Spectra Push Limits on Excess

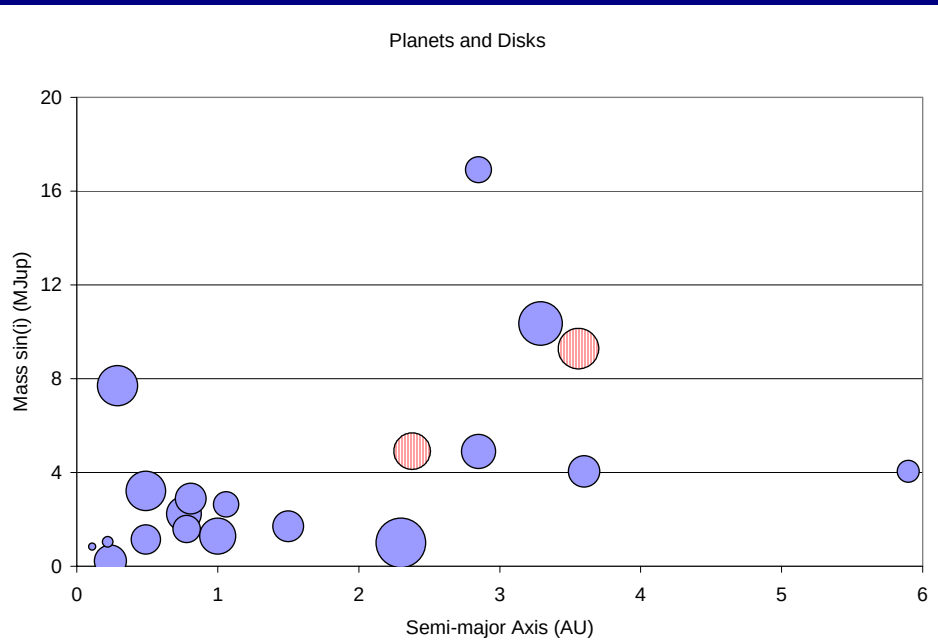


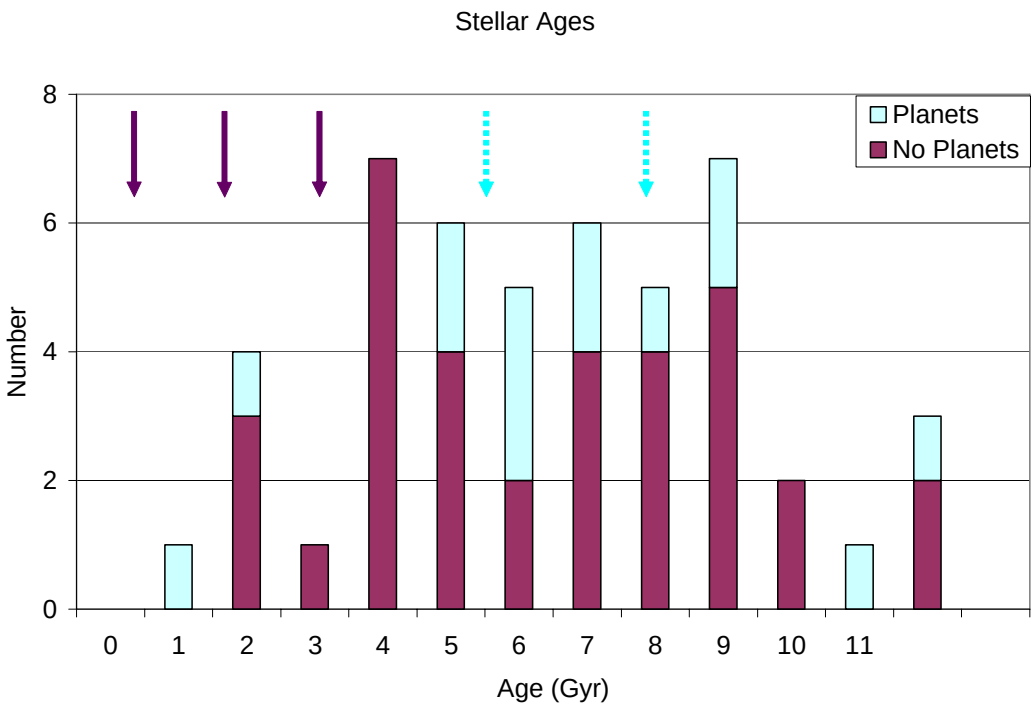
IRS Limits in Habitable Zone

- Correct initial IRS calibration by forcing fit at 21-23 μm by ×0.86±0.03 (σ_{pop}= 0.11)
- Set strong limits to longer wavelength emission <4% (1σ) for any individual star and <1% for entire sample
- $L_{dust}/L_{*}<3\times10^{-5}$ (3σ) for any individual star for material emitting at 25 μm or roughly 100 × our zodiacal cloud
  - Limit ~3× better after refined calibration or for large sample

Deviation of IRS Long Lo-1 From Kurucz Model	
Nstars	16
Δ(20-35 μm)	-0.035±0.004
σ (pop)	0.043

Some Meaningless Trends So Far



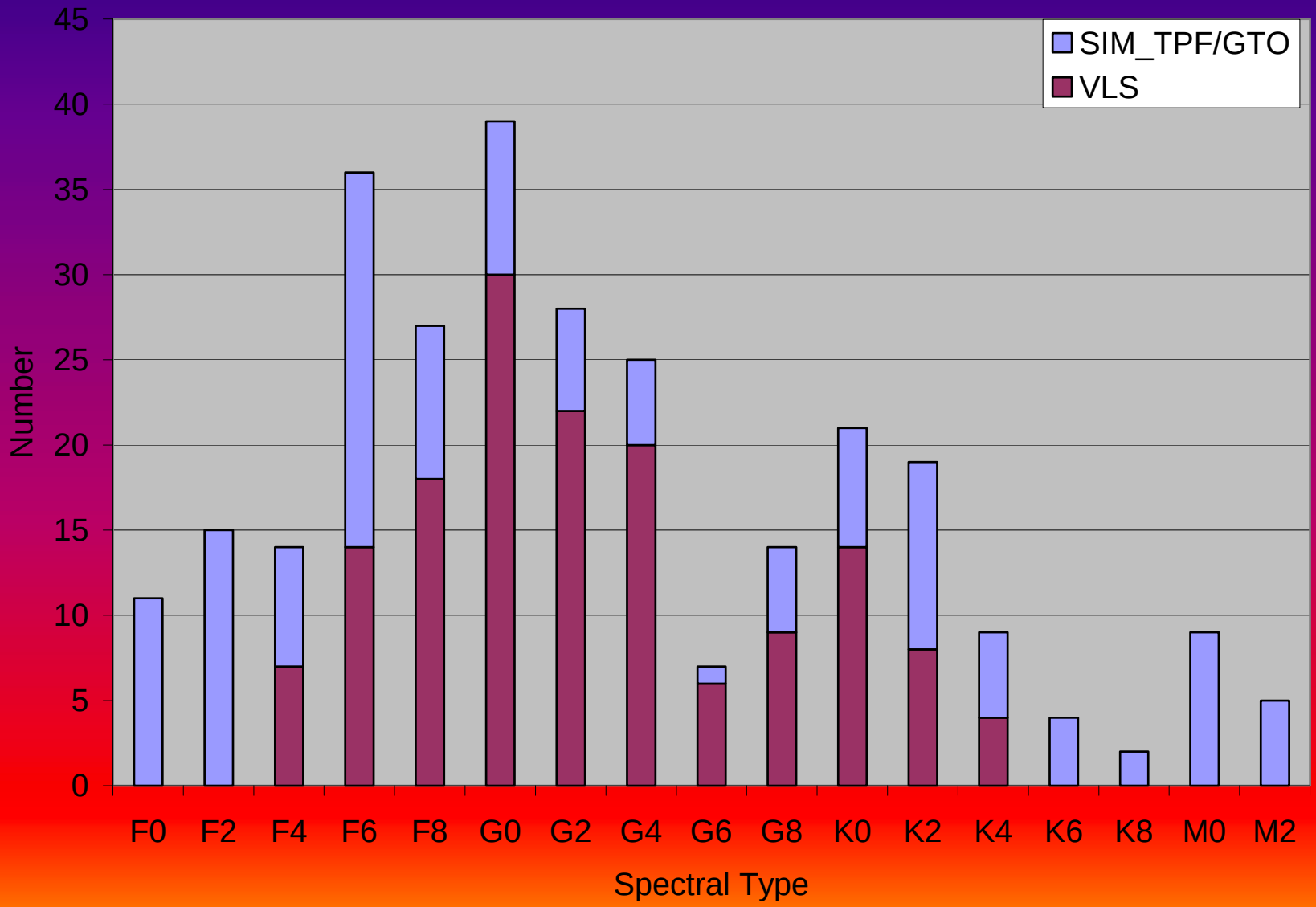


- Excess< 40 μm are rare, even for sources with 70 um excesses
- Stars with planets have larger excesses than stars without planets
- Older stars with excesses have planets
- Larger planets with eccentric orbits outside 1 AU have excesses

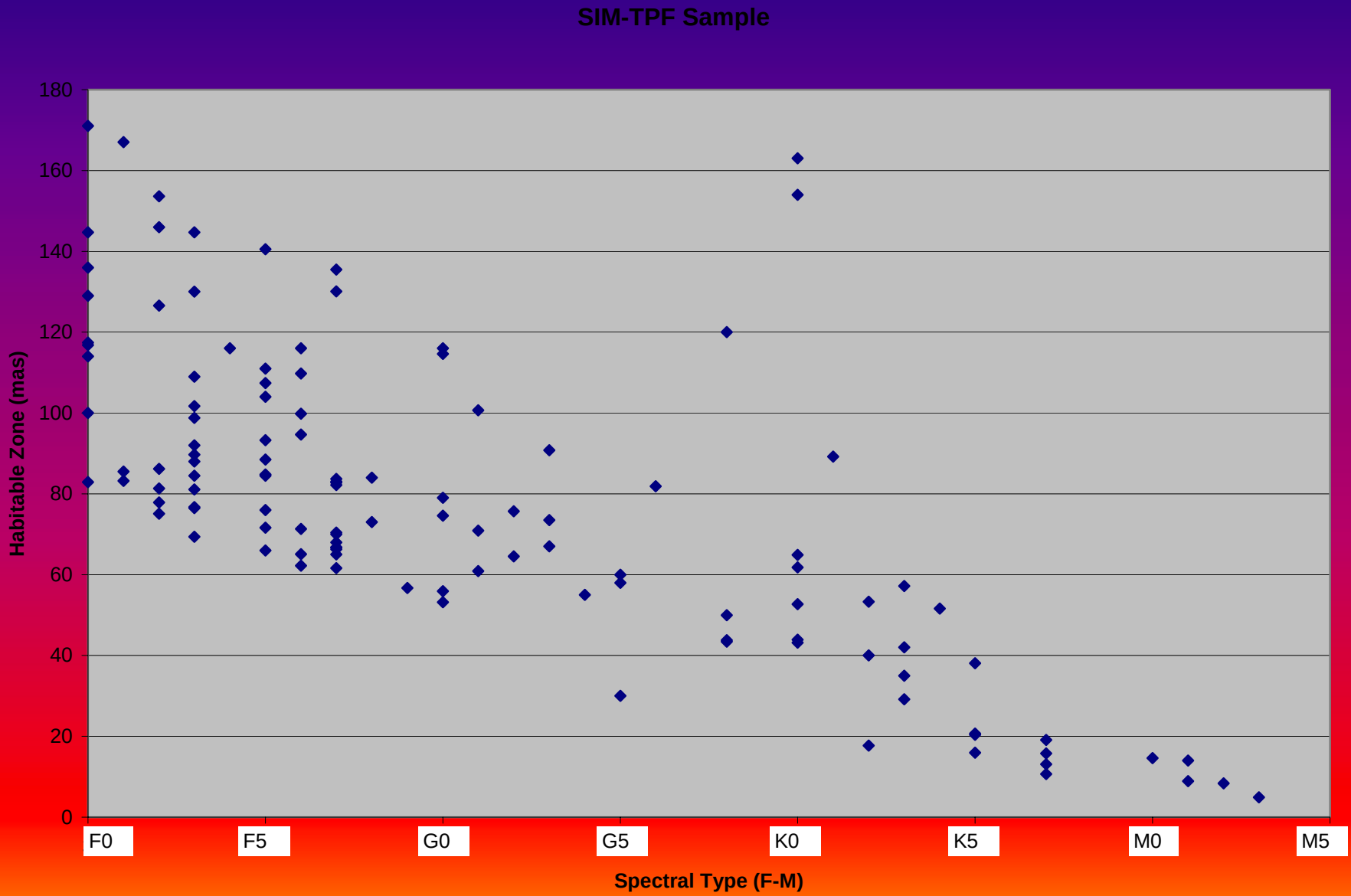
Properties of SIM-TPF Sample

- Spitzer/SIM-TPF project will survey stars for exo-zodiacal disks at 25 and 70 μm
- Steps taken to finalize the sample
  - Examined variety of TPF/SIM lists, talked with SIM PIs/CoIs to find favored stars or rejects
  - Eliminated duplicates with Legacy/GTO programs
    - This eliminated many FGK stars
    - Eliminated binaries <10 arcsec
    - A few exceptions were saved by Debra Fischer or Mike Shao
  - Required habitable zone (HZ) > 65 milliarcsec for potential TPF targets
    - Corresponds to 4 λ/D for 8 m coronagraph
    - Brings in F0-F5 stars out to 30 pc
  - Retained nearby G, K stars with 10<HZ <65 mas as suitable SIM targets
  - Rejected a few sources in parts of sky with lots of cirrus
- Final sample consists of 95 objects with small amount of time available for follow-up observations of 4-5 objects
- SIM/TPF+VLS+other GTO/Legacy surveys include 250 best TPF/SIM stars are now being observed with Spitzer.
  - Probably need to observe another 100 once final SIM targets are included

Spectral Type of Spitzer Surveys



Habitable Zone and Spectral Type

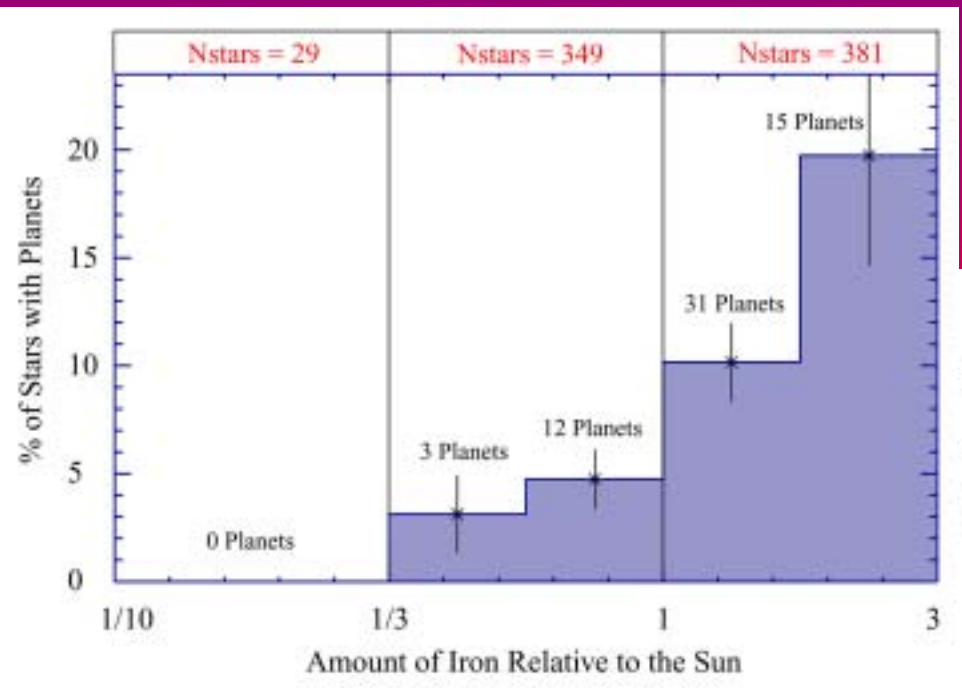


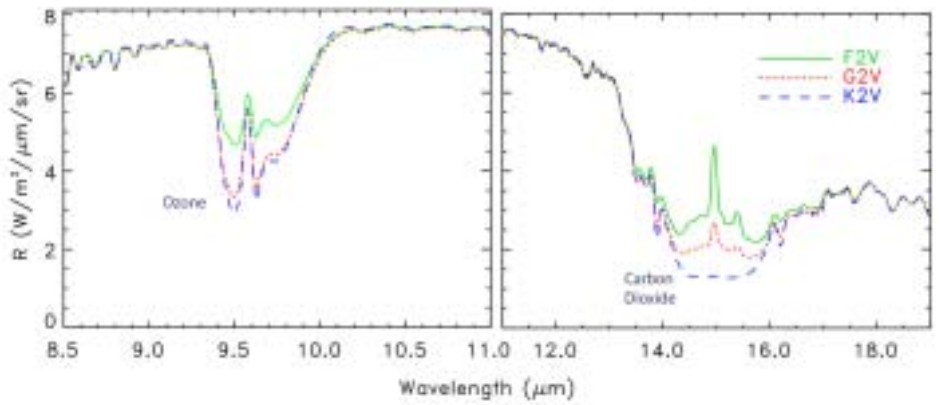
Interferometric Exo-zodiacal Observations

- Interferometers such as Keck-Keck, Large Binocular Telescope Interferometer (LBTI) and VLT-I/GENIE will reject starlight to 10^{-2}~10^{-3} to measure faint halos to probe zodiacal emission in habitable zones (0.1-3 AU)
  - 10× Solar System EZ ($\tau=10^{-6}$ at few AU) at 10 μm emits 10 mJy while star emits 280 mJy → requires few $\times 10^{-3}$ null
- Limits to sensitivity include atmosphere and telescope background, atmospheric and telescope wavefront errors.
- Stay tuned until we find real performance limits in the next week (Keck-I) and over coming 2-3 years

Properties of Stars and Planets That Might Harbor Life

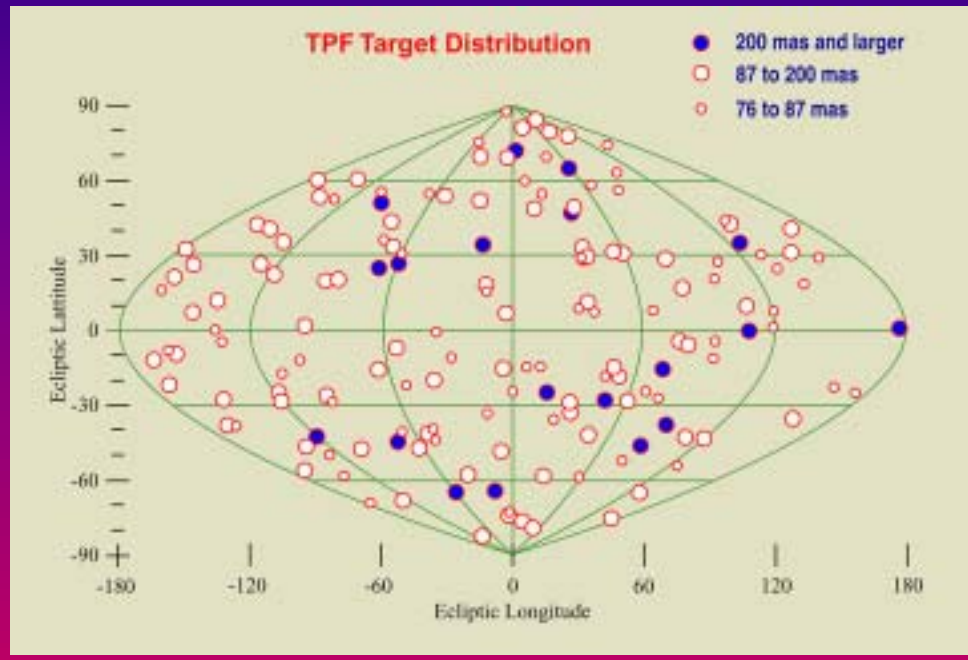
- Theoretical modeling to develop star list(s) including subset optimized for life
  - Stellar Age and lifetime
  - UV and X-ray fluxes, stellar activity
  - Metallicity
- Develop improved understanding of how to interpret TPF data in terms of physical properties of planet, habitability, presence/absence of life
  - Very low (R=4) to modest resolution
- Refine understanding of biomarkers





Catalog of Data On TPF Target Stars

- Primary information
  - Distance, luminosity, spectral type, multiplicity
  - Presence and properties of planets (from radial velocity, transits, etc.)
- Secondary information
  - Uniform set of magnitudes with <~3% accuracy
    - Need for accurate determination of exo-zodiacal dust excess
  - Stellar Rotation and orientation
  - Photospheric Variability
  - Atmospheric/chromspheric activity
  - UV brightness/variability (astrobiological implications)
  - Exozodiacal dust
- Derived properties
  - Ages---to the extent that above information can be used to infer this
  - Metallicity (correlate with planet, exozodi properties)
    - Need uniform set of spectra and models



NASA has selected IPAC team led by John Stauffer to develop STARS database for TPF and SM

"Precursor Science Roadmap" Address Important TPF Questions

- Coordinated observing/theoretical program: What is $\eta_{\oplus}$?
  - Transits (MOST,COROT, Kepler/Eddington) and micro-lensing
  - Theory extrapolating from gas giant statistics → terrestrial planets
- What are best targets dynamically?
  - Radial velocity, ground-based astrometry, SIM
  - What controls orbital stability in region of habitable zone?
  - Are solar systems "dynamically full" with planets in all stable orbits?
- What is level of exo-zodiacal emission?
  - SIRTF/Herschel/SOFIA (Kuiper belts @ 3-300 of AU)
  - Keck-I/LBT-I/VLT-I (Zodiacal clouds at ~0.3-3 AU)
  - Theory extrapolating from dust distribution → terrestrial planets
- What wavelength region should we observe?
  - Atmospheric and bio-markers from visible to mid-IR
- What are physical properties of giant planets and their influence on potentially habitable planets?
  - High resolution observations of transits, coronagraphy
- Catalog properties of target stars in coordination with ESA/ESO

5-10% of TPF budget will support scientific activities

Funding of TPF Science Community

- The project has recognized the importance of a vital scientific community and is directly supporting science at the 10% (of total project resources) level through such activities as
  - TPF Foundation Science NRA
  - Michelson Fellowship Program
  - TPF SWG
  - Coordinated activities with ESA
  - Workshops, Conferences…
  - Science Instrumentation (e.g., new RV Instrument)
- While many aspects of the precursor science program are beyond TPF's direct control, many of the TPF Roadmap questions are forefront research activities likely to be allocated time and supported by NASA, ESA and other agencies

The Goals of NASA/ESA Programs

- Search for habitable planets and life beyond the solar system
- Expand knowledge of all constituents of planetary systems as context for origin and evolution of life
  - Properties of Terrestrial Planets
  - Properties of Gas Giants out to ~5 AU
  - Properties of zodiacal clouds (comets, asteroids)
- These goals require far more than 1 mission but demand a broad range of precursor science activities and a suite of missions extending over 20 years.